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MAGNETIC ANISOTROPY OF Fe FILMS IN MgO/Cu(t_{Cu}) /Fe/Cu SYSTEMS

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Ferromagnetic resonance was employed to study the magnetic anisotropy of the Fe thin film in the MgO/Cu(t_{Cu})/Fe/Cu system. The Fe film showed strong fourfold cubic anisotropy ($H_{K_1} = 2K_1/M = 46.15$ kA/m) for $t_{\mathrm{Fe}} =$ 23 nm and $t_{\mathrm{Cu}} = 0$. The spread of the crystallographic axes $\Delta\beta = 0.5°$ was evaluated from the angular dependence of the resonance line width ΔH_{pp} ($4.4 < \Delta H_{\mathrm{pp}} < 6.4$ kA/m). Such a small mosaicity confirmed the epitaxial growth of the Fe film. The Cu buffer layer destroys this growth of the Fe film which showed only a weak anisotropy.

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1. Introduction

Ferromagnetic resonance (FMR) is a very sensitive technique yielding a lot of significant information about the magnetic properties of thin films. The analysis of the magnetic resonance fields (H_{r}) and the line widths (ΔH_{pp}) as a function of these fields orientations is a good method for estimation of the quality of growth and the magnetic anisotropy of the thin iron films grown on MgO substrates. Designation of these parameters is the initial step for further investigations of the exchange coupled Fe-based trilayers MgO/Fe/nonmagnetic film/Fe.

Thin Fe layers grown on MgO substrates have a bcc structure [1]. It was recently reported that the magnetization of such films is not enhanced [2] in contradiction to previous results [1, 3] where the effect was ascribed to the lattice dilation. The growth of Fe on Cu also shows complicated behaviour [4, 5]. The structure of the Fe film depends on its thickness and the atomic disorder [4].

The thin iron films on MgO, without the Cu buffer layer, show a strong fourfold anisotropy extorted by the substrate (001) planes. The easy magnetization [100] Fe directions are rotated by 45° with reference to the [100] MgO in-plane axes.

In this note we present results of FMR measurements for the MgO/Cu(t_{Cu})/ Fe/Cu system. The influence of the Cu buffer layer in this system on magnetic anisotropies is discussed.

2. Experimental

The Fe and Cu components were put into two separate melting pots and successively evaporated from two electron guns onto MgO(001) substrate at room temperature (RT). The pressure during evaporation was below 10^{-4} Pa and the deposition rates for Fe and Cu sublayers were about 0.02 nm/s. Thicknesses and deposition rates were monitored by a quartz crystal oscillator and controlled *ex situ* by energy dispersive analysis of X-rays (EDAX).

The microwave spectrometer used in our experiments was of the standard reflection type operating at 18.74 GHz. The FMR spectra were detected at RT as the first derivative of the absorption signal using a 1 kHz modulation field. The dc magnetic field was applied in the plane of the film and the angular position of this field was varied with accuracy of about 1°.

3. Results and discussion

Figure 1a shows the dependence of the resonance field H_r versus the angle β, between dc field direction and Fe easy axis, for the sample MgO/Fe(23 nm)/Cu(7.5 nm). The solid line is calculated from the basic resonance conditions (3), (5) or (3), (4) given in [6, 7]. We assume the bulk value of the saturation magnetization $M = 2.136$ T. The data in Fig. 1a were fitted with $M_{\rm eff} = 2.019$ T and $K_1 = 4.93 \times 10^4$ J/m^3 which is in excellent agreement with the value obtained by da Silva et al. [8].

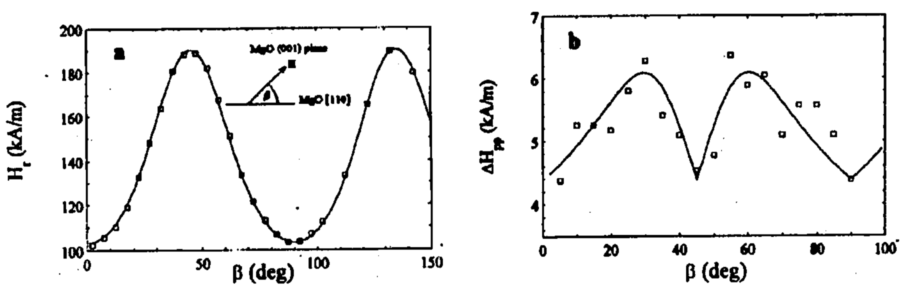

Fig. 1. Angular dependence of the *in-plane* resonance field H_r (a) and the line width $\Delta H_{\rm pp}$ (b) for the MgO/Fe(23 nm)/Cu(7.5 nm) sample. The theoretical lines are fitted with parameters: $g = 2.08$, $M_{\rm eff} = 2.019$ T, $K_1 = 4.93 \times 10^4$ J/m^3, $\acute{C}\beta = 0.5°$.

The above results suggest that the Fe film is a single crystal. The good quality of growth can be additionally confirmed by measuring of the angular dependence of the line width $\Delta H_{\rm pp}$ (peak to peak distance in the derivative of the absorption spectrum). Both the experimental data and the calculated curve are displayed in Fig. 1b. The theoretical line is obtained from the standard formula (Eq. (8) given in [6] or described in [9]). The mosaicity $\Delta\beta = 0.5°$, the spread of easy axis, is well consistent with the value 0.8° evaluated from X-ray measurements by Goryunov et al. [6]. Such a small spread of the crystallographic axes corroborates the epitaxial growth of this Fe film.

We observed that magnetic properties of the Fe film are dramatically changed for a sample when growing the Fe film on a Cu buffer layer. In order to test these effects we prepared a set of MgO/Cu(t_{Cu})/Fe(2.7 nm)/Cu(13 nm) multilayers for various thicknesses t_{Cu} of the Cu underlayer. From Fig. 2 it can be seen that the in-plane anisotropy field H_{K_1} ($= 2K_1/M$) reduces to zero or to a very small growth-induced [10] uniaxial in-plane anisotropy ($H_U = 2.78$ kA/m). This effect is probably due to the quick strain relaxation within the MgO/Cu interface in contradiction to the case of MgO/Fe films [6]. However, for a thicker film with $t_{Fe} = 13.5$ nm and the buffer layer thickness $t_{Cu} = 13$ nm we observed a small negative (according to the Fe film grown directly on MgO) fourfold anisotropy field $H_{K_1} = 5.17$ kA/m. Hence, the buffer layer rotates the Fe easy axis to the

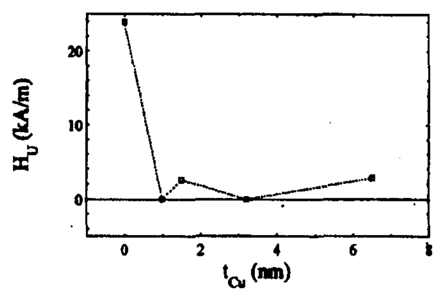

Fig. 2. Uniaxial (fourfold for $t_{Cu} = 0$) anisotropy field H_U as a function of the Cu buffer layer thickness t_{Cu} in the MgO/Cu(t_{Cu})/Fe(2.7 nm)/Cu(13 nm) samples.

direction parallel to the MgO [100] axis. It is clear that thicknesses of both layers: Cu buffer and Fe film are responsible for the magnetic properties of the samples, therefore this question demands further investigations.

4. Conclusions

In conclusion, we have studied the properties of Fe films on MgO and on MgO/Cu employing ferromagnetic resonance. The fourfold magnetic anisotropy for the first system appeared to be very strong while the latter showed only a weak anisotropy. Even a thin Cu buffer layer destroys the epitaxial growth of the Fe film.

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